

1 **CLAIMS**

2 What is claimed is:

3 1. An optical apparatus, comprising an optical element having formed therein at least
4 one set of diffractive elements and at least two channel optical waveguides, each
5 channel optical waveguide having a corresponding first end and substantially
6 confining in two transverse spatial dimensions an optical signal propagating
7 therein, wherein:

8 diffractive elements of each set of diffractive elements are distributed among
9 diffractive element subsets corresponding to each of at least two of the
10 channel waveguides;

11 each diffractive element set routes, between a corresponding pair of optical ports,
12 those corresponding portions of an optical signal propagating within the optical
13 element that are received by at least two of the channel waveguides and back-
14 diffracted within the receiving channel waveguides by corresponding diffractive
15 element subsets;

16 the channel optical waveguides are arranged so that an optical signal entering the
17 optical element at an input optical port first propagates through a region of the
18 optical element between the input optical port and the first ends of the channel
19 waveguides and is then incident on and received at least in part by the
20 corresponding first ends of at least two of the channel optical waveguides; and

21 the channel optical waveguides are arranged so that the corresponding routed
22 portions of optical signal exiting the optical element at an output optical port
23 first propagate through a region of the optical element between the first ends
24 of the channel waveguides and the output optical port.

25 2. The optical apparatus of Claim 1, wherein regions of the optical element between
26 optical ports and the first ends of the channel waveguides comprise at least one
27 slab optical waveguide, the slab waveguide substantially confining in one
28 transverse spatial dimension an optical signal propagating in two dimensions
29 therein.

- 1 3. The optical apparatus of Claim 2, wherein the slab waveguide comprises a core
2 layer surrounded by lower-index cladding layers.
- 3 4. The optical apparatus of Claim 2, wherein the slab waveguide and the channel
4 waveguides are formed on a common substrate.
- 5 5. The optical apparatus of Claim 1, wherein an optical signals propagate in three
6 dimensions in regions of the optical element between optical ports and the first
7 ends of the channel waveguides.
- 8 6. The apparatus of Claim 1, wherein relative spatial arrangement of the first ends of
9 the channel waveguides and corresponding relative phase shifts imparted on
10 back-diffracted portions of the optical signal in the channel waveguides define at
11 least in part a relative spatial arrangement of the corresponding pair of optical
12 ports.
- 13 7. The apparatus of Claim 6, wherein the corresponding longitudinal positions of the
14 diffractive element subsets along the corresponding channel waveguides at least
15 partly determine the corresponding imparted phase shifts.
- 16 8. The apparatus of Claim 6, wherein at least one channel waveguide includes a
17 corresponding static phase-shifting element that at least partly determines the
18 corresponding imparted phase shifts.
- 19 9. The apparatus of Claim 6, wherein at least one channel waveguide includes a
20 phase modulator that at least partly determines the corresponding imparted phase
21 shifts.
- 22 10. The apparatus of Claim 9, wherein the relative spatial arrangement of the
23 corresponding optical ports shifts in response to a control signal applied to the
24 phase modulator.
- 25 11. The apparatus of Claim 6, wherein:

1 at least two of the channel optical waveguides include corresponding broadband
2 reflectors that provide substantial reflectivity over an operating wavelength
3 range of the optical apparatus;
4 the broadband reflectors route, between another corresponding pair of optical
5 ports, those corresponding portions of an optical signal propagating within the
6 optical element that are received by at least two of the channel waveguides,
7 substantially transmitted by the diffractive element set, and redirected within
8 the receiving channel waveguides by the corresponding broadband reflectors;
9 and
10 wherein relative spatial arrangement of the first ends of the channel waveguides
11 and corresponding relative phase shifts imparted on redirected portions of the
12 optical signal in the channel waveguides define at least in part a relative
13 spatial arrangement of the other corresponding pair of optical ports.

14 12. The apparatus of Claim 11, wherein the corresponding longitudinal positions of the
15 broadband reflectors along the corresponding channel waveguides at least partly
16 determine the corresponding phase shifts imparted on redirected portions of the
17 optical signal.

18 13. The apparatus of Claim 11, wherein at least one channel waveguide includes a
19 corresponding static phase-shifting element that at least partly determines the
20 corresponding phase shifts imparted on redirected portions of the optical signal.

21 14. The apparatus of Claim 11, wherein at least one channel waveguide includes a
22 phase modulator that at least partly determines the corresponding phase shifts
23 imparted on redirected portions of the optical signal.

24 15. The apparatus of Claim 14, wherein the relative spatial arrangement of the other
25 corresponding pair of optical ports shifts in response to a control signal applied to
26 the phase modulator.

27 16. The apparatus of Claim 11, wherein the first pair of optical ports comprises an
28 input port and a dropped-channel port, the other pair of optical ports comprises the

1 input port and an output port, and the apparatus functions as a channel-dropping
2 demultiplexer.

3 17. The apparatus of Claim 11, wherein the first pair of optical ports comprises an
4 added-channel port and an output port, the other pair of optical ports comprises an
5 input port and the output port, and the apparatus functions as a channel-adding
6 multiplexer.

7 18. The apparatus of Claim 6, wherein:
8 at least two of the channel waveguides route, between another corresponding pair
9 of optical ports, those corresponding portions of an optical signal propagating
10 within the optical element that are received by at least two of the channel
11 waveguides, substantially transmitted by the diffractive element set, and
12 emitted from corresponding second ends of the routing channel waveguides;
13 and
14 wherein relative spatial arrangement of the first ends of the channel waveguides,
15 relative spatial arrangement of the second ends of the channel waveguides,
16 and corresponding relative phase shifts imparted on transmitted portions of the
17 optical signal by the channel waveguides define at least in part a relative
18 spatial arrangement of the other corresponding pair of optical ports.

19 19. The apparatus of Claim 18, wherein corresponding lengths of the corresponding
20 channel waveguides at least partly determine the corresponding phase shifts
21 imparted on transmitted portions of the optical signal.

22 20. The apparatus of Claim 18, wherein at least one channel waveguide includes a
23 corresponding static phase-shifting element that at least partly determines the
24 corresponding phase shifts imparted on transmitted portions of the optical signal.

25 21. The apparatus of Claim 18, wherein at least one channel waveguide includes a
26 phase modulator that at least partly determines the corresponding phase shifts
27 imparted on transmitted portions of the optical signal.

- 1 22. The apparatus of Claim 21, wherein the relative spatial arrangement of the other
2 corresponding pair of optical ports shifts in response to a control signal applied to
3 the phase modulator.
- 4 23. The apparatus of Claim 18, wherein the first pair of optical ports comprises an
5 input port and a dropped-channel port, the other pair of optical ports comprises the
6 input port and an output port, and the apparatus functions as a channel-dropping
7 demultiplexer.
- 8 24. The apparatus of Claim 18, wherein the first pair of optical ports comprises an
9 added-channel port and an output port, the other pair of optical ports comprises an
10 input port and the output port, and the apparatus functions as a channel-adding
11 multiplexer.
- 12 25. The apparatus of Claim 18, wherein the corresponding second ends of the
13 channel waveguides are structurally adapted for optical coupling with one optical
14 port of the other corresponding pair of optical ports.
- 15 26. The apparatus of Claim 6, wherein the corresponding first ends of the channel
16 waveguides are structurally adapted for optical coupling with the corresponding
17 pair of optical ports.
- 18 27. The apparatus of Claim 26, wherein the corresponding first ends of the channel
19 waveguides are flared.
- 20 28. The apparatus of Claim 26, wherein the corresponding first ends of the channel
21 waveguides are tapered.
- 22 29. The apparatus of Claim 26, wherein the corresponding first ends of the channel
23 waveguides have segmented cores.
- 24 30. The apparatus of Claim 26, wherein end faces of the corresponding first ends of
25 the channel waveguides are curved.

- 1 31. The apparatus of Claim 1, wherein the diffractive element set imparts at least one
2 of spectral characteristics and temporal characteristics onto the corresponding
3 back-diffracted portions of the optical signal, thereby determining at least in part at
4 least one of spectral characteristics and temporal characteristics of the routed
5 portion of the optical signal.
- 6 32. The apparatus of Claim 31, wherein the diffractive element subsets impart
7 substantially the same characteristics onto the corresponding back-diffracted
8 portions of the optical signal.
- 9 33. The apparatus of Claim 31, wherein the diffractive element subsets impart differing
10 characteristics onto the corresponding back-diffracted portions of the optical
11 signal.
- 12 34. The apparatus of Claim 31, wherein corresponding resonance wavelengths for the
13 corresponding back-diffracted portions of the optical signal are determined at least
14 in part by longitudinal spacing of the diffractive elements of the corresponding
15 subsets.
- 16 35. The apparatus of Claim 34, wherein the longitudinal spacing is substantially
17 constant over the diffractive element set.
- 18 36. The apparatus of Claim 34, wherein the longitudinal spacing is substantially
19 constant within each of the diffractive element subsets.
- 20 37. The apparatus of Claim 34, wherein the longitudinal spacing varies over the
21 diffractive element set.
- 22 38. The apparatus of Claim 34, wherein the longitudinal spacing varies within each
23 diffractive element subset.
- 24 39. The apparatus of Claim 31, wherein at least one of amplitude and phase of sub-
25 portions, diffracted by single diffractive elements, of the corresponding back-
26 diffracted portions of the optical signal is controlled by at least one of relative

1 positioning of the individual diffractive elements and configuration of the individual
2 diffractive elements.

3 40. The apparatus of Claim 31, wherein the diffractive element set imparts spectral
4 characteristics onto the back-diffracted portions of the optical signal, the optical
5 apparatus thereby functioning as a spectral filter.

6 41. The apparatus of Claim 40, wherein the optical apparatus functions as a
7 multiplexer/demultiplexer.

8 42. The apparatus of Claim 41, wherein:
9 the corresponding pair of optical ports comprise a multiplexing optical port and at
10 least one of an input optical port and an output optical port;
11 wherein relative spatial arrangement of the first ends of the channel waveguides
12 and corresponding relative phase shifts imparted on back-diffracted portions of
13 the optical signal in the channel waveguides define at least in part a relative
14 spatial arrangement of the multiplexing optical port and at least one of the
15 input optical port and the output optical port;
16 at least two of the channel optical waveguides include corresponding broadband
17 reflectors that provide substantial reflectivity over an operating wavelength
18 range of the optical apparatus;
19 the broadband reflectors route, between the input optical port and the output
20 optical port, those corresponding portions of an optical signal propagating
21 within the optical element that are received by at least two of the channel
22 waveguides, substantially transmitted by the diffractive element set, and
23 redirected within the receiving channel waveguides by the corresponding
24 broadband reflectors; and
25 relative spatial arrangement of the first ends of the channel waveguides and
26 corresponding relative phase shifts imparted on redirected portions of the
27 optical signal in the channel waveguides define at least in part a relative
28 spatial arrangement of the input optical port and the output optical port.

29 43. The apparatus of Claim 41, wherein:

1 the corresponding pair of optical ports comprise a multiplexing optical port and at
2 least one of an input optical port and an output optical port;
3 wherein relative spatial arrangement of the first ends of the channel waveguides
4 and corresponding relative phase shifts imparted on back-diffracted portions of
5 the optical signal in the channel waveguides define at least in part a relative
6 spatial arrangement of the multiplexing optical port and at least one of the
7 input optical port and the output optical port;
8 at least two of the channel waveguides route, between the input optical port and
9 the output optical port, those corresponding portions of an optical signal
10 propagating within the optical element that are received by at least two of the
11 channel waveguides, substantially transmitted by the diffractive element set,
12 and emitted from corresponding second ends of the routing channel
13 waveguides; and
14 relative spatial arrangement of the first ends of the channel waveguides, relative
15 spatial arrangement of the second ends of the channel waveguides, and
16 corresponding relative phase shifts imparted on transmitted portions of the
17 optical signal in the channel waveguides define at least in part a relative
18 spatial arrangement of the input optical port and the output optical port.

19 44. The apparatus of Claim 31, wherein the diffractive element set imparts temporal
20 characteristics onto the corresponding back-diffracted portions of the optical
21 signal, the optical apparatus thereby functioning as a temporal encoder.

22 45. The apparatus of Claim 1, further comprising multiple diffractive element sets,
23 diffractive elements of each set of diffractive elements being distributed among
24 diffractive element subsets corresponding to each of at least two of the channel
25 waveguides, each diffractive element set imparting at least one of spectral
26 characteristics and temporal characteristics onto the corresponding back-diffracted
27 portions of the optical signal, thereby determining at least in part at least one of
28 spectral characteristics and temporal characteristics of the corresponding routed
29 portions of the optical signal.

- 1 46. The apparatus of Claim 45, wherein at least two sets of diffractive elements impart
2 distinct characteristics onto their respective back-diffracted portions of the optical
3 signal.
- 4 47. The apparatus of Claim 45, wherein at least two of the multiple diffractive element
5 sets are overlaid.
- 6 48. The apparatus of Claim 45, wherein at least two of the multiple diffractive element
7 sets are stacked.
- 8 49. The apparatus of Claim 45, wherein at least two of the multiple diffractive element
9 sets are interleaved within at least one common channel waveguide.
- 10 50. The apparatus of Claim 45, wherein at least two of the multiple diffractive element
11 sets are interleaved among multiple of the channel waveguides.
- 12 51. The apparatus of Claim 50, wherein each channel waveguide has at most one
13 subset of diffractive elements.
- 14 52. The apparatus of Claim 1, wherein routing of the back-diffracted portions of the
15 optical signal exhibits a designed dependence on polarization of the optical signal.
- 16 53. The apparatus of Claim 52, wherein routing of the back-diffracted portions of the
17 optical signal is substantially independent of the polarization of the optical signal.
- 18 54. The apparatus of Claim 1, wherein routing of the back-diffracted portions of the
19 optical signal exhibits a designed dependence on temperature of the optical
20 element over an operating temperature range.
- 21 55. The apparatus of Claim 54, wherein routing of the back-diffracted portions of the
22 optical signal is substantially independent of the temperature of the optical element
23 over an operating temperature range.

- 1 56. The apparatus of Claim 1, wherein routing of the back-diffracted portions of the
2 optical signal includes conjugate-ratio imaging of one of the corresponding pair of
3 optical ports onto the other of the corresponding pair of optical ports.
- 4 57. The apparatus of Claim 1, wherein routing of the back-diffracted portions of the
5 optical signal includes propagation between the ends of the channel waveguides
6 and at least one of the corresponding pair of optical ports as an optical mode
7 substantially collimated in an unconfined transverse dimension.
- 8 58. The apparatus of Claim 1, further comprising a second similar optical element
9 having formed therein at least one set o diffractive elements and at least two
10 channel optical waveguides, wherein an output optical port of the first optical
11 element serves as an input optical source for an input optical port of the second
12 optical element.